PHYS 543 – Quarks and Leptons

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Grader: TBD
Class Hours: Tuesday & Thursday 1:00 - 2:15 pm
Class Location: TBD
Office Hours: TBD

Course Objectives and Learning Outcomes

This course is a technical introduction to elementary particle physics. Our understanding of the elementary particles ballooned in the 20th century thanks to both experimental advances like high-energy collider experiments and theoretical developments like quantum field theory. Today elementary particle physics is still an extremely active field of research with new experimental opportunities on the horizon and unsolved mysteries to puzzle over.

The key goals of this course are as follows.

- Students will become conversant in the language of particle physics, making it easier for them to follow research presentations and read research articles.
- Students will learn how matter is structured (molecules, atoms, nuclei) and how it interacts (radioactivity, scattering).
- Students will understand how the elementary constituents of matter (quarks, leptons) and the fundamental forces (electromagnetism, nuclear forces) are embedded into the Standard Model of Elementary Particles.
- Students will learn to calculate scattering cross sections and decay rates using Feynman rules and Feynman diagrams.
- Students will develop the knowledge base necessary to pursue research in nuclear physics, elementary particle physics, or particle astrophysics.

Prerequisites

This course is a continuation of *PHYS 542 - Intro to Nuclear & Particle Physics*. Students who have not taken PHYS 542 should be familiar with concepts such as radioactive decay, scattering cross section, electromagnetic radiation, the structure of atoms, particle-antiparticle partners, the four fundamental forces, and the Standard Model of elementary particles. Students will benefit from a strong background in **classical mechanics** (*e.g.*, scattering cross section), **special relativity** (*e.g.*, 4-vector, Minkowski metric, Lorentz group), **electromagnetism** (*e.g.*, stress-energy tensor), and **quantum mechanics** (*e.g.*, Hamiltonian, spin/helicity). No in-depth knowledge of advanced topics is assumed, and the course will be accessible to first- and second-year graduate students.

Grade Policies

Student performance will be evaluated based on the following:

40% Homework assignments.

30% Recitation.

30% Final exam.

Homework Assignments

Working through a calculation carefully gives us the opportunity to develop a deeper understanding of the underlying physics. When our understanding doesn't match the calculation, observation, or measurement, then it's time to learn something new about physics. This is how research gets done!

We will have **approximately 7 homework assignments** throughout the semester, with an assignment due every other week. Assignments will primarily consist of problems, but may also include a short essay response question.

Each student will be allowed **one late homework submission** during the semester. This is to help alleviate pressure from too many assignments being due on the same week. You should let me know in advance when you'd like to use your one 'free pass.' The assignment due date for you will be pushed back by 2 days. Otherwise, unexcused tardiness will result in a reduction in your grade for the assignment at a rate of 20% per day (including weekends). In the event of emergency or illness, please notify me as early as possible to discuss accomodations.

In completing the assignments, students are encouraged to draw on the following resources: lecture notes, text books, published journal articles, and the professor (come to office hours!). Students *may not* look up the solution online or confer with students who took the class in past years. Students in the class are strongly encouraged to collaborate with one another on the assignments, by discussing the problems together. However, each student must write up and submit their homework separately, and they must acknowledge where they benefited from collaboration with other students in the writeup. (*E.g.*, "Dave McKeen pointed out that you can use Wick's theorem here.") Students are free to submit homework assignments as either handwritten text/equations/drawings (please write neatly!) or typed (LaTeX). Students are free to use digital computing tools (*e.g.* Mathematica) to assist the calculation if needed and to generate plots.

All assignments will be submitted electronically. Assignments must be submitted as **a single pdf file** using Canvas.

Recitation

There are two 80-minute lectures per week. In advance of these meetings, all of the students will be assigned a section of reading from Thomson's book, and a pair of students will be asked to present the material that they've studied in front of the class. In other words, for each meeting you are expected to have prepared your notes such that you can stand in front of the class and explain the

assigned chapter or sections to your fellow students. These student presentations will contribute to your final grade, based on clarity of presentation and depth of understanding.

Your performance will be evaluated based on the following factors:

- *Understanding.* Did you read the material carefully? Does it seem like you read the material carefully? Is the content of the presentation correct?
- *Effective communication.* Were you able to explain the material in a clear and concise manner? Don't try to talk about every detail in the reading. It's important to identify the key ideas/equations and highlight these points.
- *Style.* Were you able to speak slowly and clearly? Did you convey some level of excitement or interest in the material? What was the medium ... whiteboard, powerpoint, handwritten notes, scrolling through the textbook pdf?
- *Keep to time.* Were you able to get through the assigned material in the allotted time? Remember that you don't have to (and probably shouldn't) try to discuss every topic and formula in the assigned reading. You want to identify the key points and focus on them.
- *Discussion, Q&A.* Were you able to answer questions from the other students? Did you bring your own questions for discussion?

Final Exam

There will be a take-home or oral final exam. Students can use their lecture notes and the textbook, but they cannot work together or discuss with one another.

Absence & Attendance Policies

Students are encouraged to bring their own unique perspective on the material to lectures and share their viewpoint with the class through questions and comments. Attendance at lecture is required.

Rice Honor Code

In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-system-handbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

Disability Resource Center

If you have a documented disability or other condition that may affect academic performance you should: 1) make sure this documentation is on file with the Disability Resource Center (Allen Center, Room 111 / adarice@rice.edu / x5841) to determine the accommodations you need; and 2) talk with me to discuss your accommodation needs.

Title IX Responsible Employee Notification

Rice University cares about your wellbeing and safety. Rice encourages any student who has experienced an incident of harassment, pregnancy discrimination or gender discrimination or relationship, sexual, or other forms interpersonal violence to seek support through The SAFE Office. Students should be aware when seeking support on campus that most employees, including myself, as the instructor/TA, are required by Title IX to disclose all incidents of non-consensual interpersonal behaviors to Title IX professionals on campus who can act to support that student and meet their needs. For more information, please visit safe.rice.edu or email titleixsupport@rice.edu.

Resources

- *Modern Particle Physics* by **Mark Thomson:** An excellent, comprehensive introduction to particle physics and the Standard Model. We will be following this book closely, so please pick up a copy.
- *Quarks and Leptons* by **F. Halzen and S. Martin:** A classic introduction to the basics of particle physics. Also thanks to its smaller size, it makes a very handy reference for grabbing formulas when doing research.
- *Modern Elementary Particle Physics: The Fundamental Particles and Forces* by **G. Kane:** A clear introduction to the subject that's also accessible for undergraduates.
- *Introduction to Elementary Particles* by **D. Griffiths:** A nice read from an excellent author.
- *Lectures on Quantum Field Theory* by **D. Tong:** QFT is the language of particle physics. If you want to know more about this topic, Tong's very nice lecture notes are available online: http://www.damtp.cam.ac.uk/user/tong/qft.html.

Course Content

Topics covered in this course (and their approximate order of presentation) will include

- The Standard Model of Elementary Particles
- Scattering and decay
- The Dirac equation. Particle-antiparticle pairs

- Feynman diagrams
- Quantum electrodynamics (QED)
- Scattering in QED: Coulomb, Compton, bremstrahlung
- Deep inelastic scattering (DIS)
- Quarks and partons
- Quantum Chromodynamics (QCD)
- The weak interaction. W- and Z-bosons.
- Neutrinos and their flavor oscillations.
- The Higgs boson.
- Flavor physics and CP violation.